# METHODS AND COMPOSITIONS FOR OPTIMIZING INTERFACIAL PROPERTIES OF MAGNETORESISTIVE SENSORS

## FIELD OF THE INVENTION

This invention relates to methods and compositions for optimizing the interfacial properties of magnetoresistive sensors, and specifically data storage devices such as spin valve sensors and giant magnetoresistive (GMR) sensors.

## DESCRIPTION OF THE PRIOR ART

Significant progress has occurred over the past two decades in the design of multilayered nanostructured thin film systems. Large GMR current-in-plane (CIP) effects have been described in a Fe/Cr multilayered system, approximating a magnetoresistance effect ($\Delta R/R$) of 100 percent, which is a change by a factor of two in resistance with an adequate external field. Since then, many other multilayer GMR and spin valve sensors have been explored. To date, the highest GMR effect is in the Fe/Cr system and is approximately 150 percent at a measurement temperature of 5° K., and remains the largest value observed at any temperature to date. Both the GMR and spin valve effects are characterized by $\Delta R/R$, which is defined as the change in resistance divided by the initial resistance, and is $(R_0-R_H)/R_0$, where $R_0$ is the sensor resistance without an external magnetic field and a $R_H$ is the resistance at a minimum external field required to maximize $\Delta R/R$.

Numerous theoretical studies have attempted to explain the behavior of spin valve and GMR effects. However, there does not currently exist an explanation of the main factors controlling the magnitude of the sensor response, as characterized by $\Delta R/R$, as it relates to the required properties of the conductive spacers and ferromagnetic (FM) layers constituting such device. Experimental efforts have been largely based on trial and error, by investigating with various combinations of FM layers and conductive spacer layers. None of the previous work has yielded quantitative guidelines for the maximization of $\Delta R/R$ for spin valve or GMR sensors by providing selection criteria for the layer compositions of the FM material and the conductive spacer.

## SUMMARY OF THE INVENTION

An object of this invention is to provide means and methods for optimizing the manufacturing process of various magnetoresistive devices, including but not limited to thin film devices such as sensors used in data storage devices.

Another object of this invention is to provide guidelines for optimizing the selection of multilayer compositions by matching or minimizing the difference in the electronegativities ($\chi$) of adjacent ferromagnetic layers and conductive spacers.

Still another object of the present invention is to maximize the signal output, as represented by $\Delta R/R$ of spin valve sensors and GMR sensors.

A further object of this invention is to maximize the thermal stability of spin valve sensors and GMR sensors.

Yet another object of this invention is to maximize the corrosion resistance of spin valve sensors and GMR sensors.

Another object of the invention is to provide conductive spacers which minimize electromigration in the FM and spacer layers, which extend the useful lifetimes of spin valve and GMR sensors.



Another object is to provide for multiple interfacial matching of an FM layer with its contacting conductive spacers. In accordance with this invention, spin valve sensors and GMR sensors are made with layers of FM material and conductive spacers interposed between the FM layers. The difference in electronegativities between the layers and spacers is minimized. A relatively low resistivity and/or a large mean free path is provided by the conductive spacer material. As a result of these conditions, the $\Delta R/R$ of the sensor is maximized. The novel sensor is also corrosion resistant, exhibits greater chemical and thermal stability, and signal output of the sensor device is increased.

A method for optimizing the interfacial properties of a magnetoresistive sensor, such as a GMR or spin valve, is disclosed. The method includes selecting one or more FM layers having at least a first electronegativity, and selecting one or more conductive spacers having at least a second electronegativity, such that the selecting steps include the step of substantially matching or minimizing the difference between the first and second electronegativities and thereby minimizing the difference between the electronegativities of the selected spacers and FM layers.

## BRIEF DESCRIPTION OF THE DRAWING

The invention will be described in greater detail with reference to the drawings in which:

**FIG. 1** is a cross-sectional view depicting a spin valve sensor made in accordance with this invention;

**FIG. 2** is a cross-sectional view depicting a GMR sensor made in accordance with this invention;

**FIG. 3** is a graph plotting a relationship between a square root of the absolute value of an electronegativity difference (i.e., $|\Delta\chi|^{1/2}$) versus $\Delta R/R$ for spin valve sensors with various ferromagnetic/conductive spacer interfaces;

**FIG. 4** illustrates three curves plotting the relationship between $|\Delta\chi|^{1/2}$ versus $\Delta R/R$ for various spin valve sensors at different temperatures;

**FIG. 5** illustrates three curves plotting the relationship between $|\Delta\chi|^{1/2}$ versus $\Delta R/R$ for various GMR sensors illustrating the first, second and third peaks of GMR response;

**FIG. 6** illustrates a curve plotting the relationship between $|\Delta\chi|^{1/2}$ versus $\Delta R/R$ for various GMR sensors having various crystal structures.

**FIG. 7** is a chart that illustrates various exemplary combinations and compositions of FM layers and spacers for use in spin valve and GMR sensors;

**FIG. 8** illustrates two curves plotting the electrical resistivity in microohm-cm versus the atomic composition for a Cu—Au alloy system;

**FIG. 9** illustrates two graphs plotting the electrical resistivity in microohm-cm versus the atomic composition for a CuPt alloy system;

**FIG. 10** illustrates a use of random crystal orientation in a spin valve sensor made according to the present invention;

**FIG. 11** illustrates a use of preferred crystal orientation in a spin valve sensor made according to the present invention;

**FIG. 12** is a cross-sectional view of a spin valve sensor with compound interfaces made according to the present invention; and

**FIG. 13** is a cross-sectional view of a giant magnetoresistive sensor with compound interfaces made according to the present invention.

Similar numerals refer to similar elements in the drawings. It should be understood that the sizes of the different